SUNSPOTS AND TERRESTRIAL TEMPERATURE IN THE UNITED STATES.[1]

By ALFRED J. HENRY, Meteorologist.

[Weather Bureau, Washington, April 16, 1923.]

SYNOPSIS.

This study has for its object a determination of the magnitude of fluctuations in terrestrial temperature in the United States that might be attributed to changes in the intensity of solar radiation; a less important object is to discover whether variations in the annual mean temperature of a limited region may be safely taken as representative of a much larger area in which the smaller area may be situated.

The method followed was that of determining for one each year the departure from the normal of the annual mean temperature for that year, combining these departures to form group means, etc.

The outstanding feature of the annual deviations for the United States is the evidence of short period variations within the 11-year sun spot cycle. For a time there seems to have been alternating warm and cold years and again the cycle, cold-warm would be completed in three, four, or five years. The magnitude of these short period fluctuations of course varies in an irregular manner but it must be remembered that on the average of nearly 100 years the average annual deviation of the temperature from the normal in the United States is close to 0.7° F.

For the period 1870–1921, the parallelism between terrestrial temperatures and variations in sun spots is fairly well marked, a heat maximum corresponding to a minimum of sun spots and vice versa. Previous to that period, however, the parallelism is not so good and there are several cases where the temperature variation is in the opposite sense to that expected. The average deviation for the 10 epochs of minimum spots comes out as a small fraction of a degree Fahrenheit in a negative sense because of the low temperature at spot minimum of 1843 and 1856, respectively. For the 10 epochs of spot maximum, 1816 and 1837 were unusually cold as was to be expected, on the other hand 1870 a year of a large number of spots high temperatures prevailed, as was also the case in 1848, 1860, and 1906.

As the writer has previously stated it is next to impossible to disentangle the network of influences which produce terrestrial temperature changes. Until some means of allowing for the influence of the secondary circulation (the movement of cyclones and anticyclones) is found it is hopeless to seek for effects of changes in the intensity of solar radiation in the Temperate Zone of the Northern Hemisphere.

In announcing the subject of this paper I feel inclined to apologize for threshing over so much old straw; nevertheless it seems worth while to make a brief study of the subject, using only the homogeneous system of temperature observations of the United States Weather Bureau and in addition those collected and reduced by the Smithsonian Institution for the period ending with 1870. Hitherto progress in arriving at unequivocal results has been retarded by the lack of homogeneous temperature data for extended regions as well as to other causes. Unfortunately large portions of the earth's surface are without records of long series temperature observations made under standard conditions of exposure and with standard instruments, and this drawback is more serious than is generally realized. Some idea of the paucity of dependable observations may be had when it is remembered that so late as the year 1910, when the first volume of Reseau Mondial became available there were but 111 normal temperature records in a zone 60° wide encircling the globe with the Equator as its center. That number rose to 134 for the 1914 volume, the last one received. Many of these stations, however, are grouped in India and the adjacent islands. The great tropical areas of Africa and South America are almose devoid of meteorological stations except for narrow fringes of the coast. At least five-sixths of the Tropics is composed of a water surface and is not therefore adequately represented by meteorological stations.

I have confined my work almost wholly to the observational material for the United States, or substantially that part of the earth's surface between 75° and 125°, west longitude, and the parallels of 30° to 50°, north latitude.

At the outset it has been assumed that when the temperature of any considerable part of the earth's surface is decidedly above or below the normal, it is reasonable to attribute that condition to changes in the intensity of solar radiation. My first step was therefore to obtain the annual deviation of the temperature from the normal for as many points as possible within the above-described area.

In the early part of the nineteenth century meteorological observations in the United States were confined to the eastern seaboard and near-by places. By 1816 observations were available for but 12 points all in the East. The number increased rather slowly in the ensuing 10 years with this important exception: In the early twenties the Surgeon General of the Army directed the taking of meteorological observations at Army posts, some of which were on the western frontiers. By 1830 the total number of observing stations had risen to 52, practically all east of the Rocky Mountains. That number was further increased to 94 in 1859, just previous to the War between the States; it fell off during that war and was about 70 when the Federal Government organized a weather service late in the year 1870.

I have used the annual means published in Weather Bureau Bulletin S, 1873 to 1905, and the series was brought down to date by applying a correction to the published means found in the annual reports and the MONTHLY WEATHER REVIEW to reduce them to means deduced from 24 hourly observations. I make this explanation in the interest of those who may wish to bring the temperature data of Bulletin S down to date. The published means for the years 1906–1922 have been deduced from the daily extremes; appropriate corrections to reduce to true means are given in Bulletin S, Table 1.

The annual deviation for each year beginning with 1780 is given in Table 1 below. No attempt has been made to weight the earlier years on account of the few observations used but the number of stations used in obtaining the deviation is given. Little importance is attached to the early part of the record and it is given simply for what it is worth.

The mean annual deviation of temperature for the United States as a geographic unit, counting from 1826 only, is very close to 0.7° F. (0.4° C.). The greatest positive deviation in the ninteenth century was 2.9° F. (1.6° C.) in 1828, the greatest negative was 2.6° F. (1.4° C.) in 1836. These, the greatest deviations in a century of observations, fall within less than 10 years of each other. Comparing the above dates with the general temperature distribution in the North Temperate Zone, for example, it would appear that for the much greater area the maximum of temperature occurred in 1822 and for the Tropics in 1833. The minimum temperature for the North Temperate Zone occurred in 1816, but in the Tropics it was deferred until 1837, the same year as in the United States.

[1] Presented before American Meteorological Society at Washington, D. C., Apr. 16, 1923.

TABLE 1.—*Mean annual deviation of temperature from normal for the United States as a geographic unit.*

[Figures without sign are plus.]

Number of stations.	Year.	Mean annual deviation, °F.	Number of stations.	Year.	Mean annual deviation, °F.	Number of stations.	Year.	Mean annual deviation, °F.
1	1750	−0.9	7	1812	−2.2	67	1867	0.0
1	1751	0.8	9	1813	0.4	68	1868	−0.9
1	1752	1.4	9	1814	0.0	66	1869	−0.5
1	1753	0.9	8	1815	−1.0	67	1870	1.7
1	1754	1.9	12	1816	−1.7	68	1871	0.9
1	1755	−2.3	13	1817	−1.5	90	1872	−0.8
1	1756	1.1	12	1818	−0.6	82	1873	−0.5
1	1757	−0.2	11	1819	1.0	82	1874	0.6
1	1758	−1.6	14	1820	−0.1	82	1875	−1.2
1	1759	−0.8	14	1821	−0.6	82	1876	−0.1
1	1767	0.5	13	1822	0.9	82	1877	0.9
1	1768	−1.2	14	1823	−0.6	82	1878	1.4
1	1769	−0.9	14	1824	0.6	82	1879	0.9
1	1770	−0.3	14	1825	2.0	82	1880	−0.4
1	1771	−0.9	32	1826	1.8	82	1881	0.7
1	1772	−0.2	38	1827	0.7	82	1882	0.2
1	1773	2.0	40	1828	2.9	82	1883	−0.7
1	1774	0.2	40	1829	−0.6	82	1884	−0.5
1	1775	1.7	52	1830	1.7	82	1885	−0.4
1	1776	0.8	53	1831	0.4	82	1886	−0.4
1	1777	−1.7	55	1832	0.1	82	1887	0.2
1	1778	....	62	1833	0.4	82	1888	−0.3
1	1779	....	61	1834	0.6	82	1889	0.7
1	1780	0.7	65	1835	−1.6	82	1890	0.4
2	1781	1.8	60	1836	−2.6	82	1891	0.1
1	1782	0.1	63	1837	−1.8	82	1892	−0.6
2	1783	0.9	63	1838	−1.6	82	1893	−0.9
1	1784	−1.7	67	1839	0 0	82	1894	0.1
1	1785	−1.3	74	1840	0.0	82	1895	−0.8
2	1786	−0.5	75	1841	−0.5	82	1896	0.6
2	1787	0.3	79	1842	0.1	82	1897	0.2
3	1788	−0.1	84	1843	−1.2	82	1898	0.1
3	1789	−0.1	82	1844	−0.2	82	1899	−0.3
5	1790	0.0	86	1845	0.3	82	1900	1.3
5	1791	0.8	76	1846	1.3	82	1901	0.4
5	1792	−0.5	73	1847	−0.3	82	1902	0.1
4	1793	2.1	71	1848	0.4	82	1903	−0.6
4	1794	1.3	70	1849	−0.3	82	1904	−0.5
5	1795	1.3	71	1850	0.2	82	1905	−0.4
6	1796	−0.7	76	1851	0.3	82	1906	0.4
4	1797	−0.7	72	1852	0.1	82	1907	−0.2
5	1798	0.4	67	1853	0.4	82	1908	0.6
5	1799	−0.3	77	1854	1.1	82	1909	0.1
5	1800	0.8	86	1855	0.0	82	1910	0.9
5	1801	1.5	93	1856	−1.8	82	1911	0.4
5	1802	2.1	86	1857	−1.3	82	1912	−0.9
5	1803	1.2	86	1858	0.2	82	1913	0.5
5	1804	−0.3	94	1859	−0.3	82	1914	0.6
5	1805	1.6	82	1860	0.6	82	1915	0.4
5	1806	−0.3	70	1861	0.4	82	1916	−0.5
6	1807	−1.1	61	1862	−0.1	82	1917	−1.3
6	1808	−0.4	68	1863	0.1	82	1918	0.5
6	1807	−1.0	67	1864	0.0	82	1919	0.4
7	1810	0.0	64	1865	1.0	82	1920	−0.3
7	1811	1.0	57	1866	−0.3	82	1921	2.4

fluctuations in the entire series of years. The small table below presents the annual deviations for the years in question. The large deviations shown in that table can not be very closely associated with the spottedness of the sun, except that those for 1837 synchronize with the epoch of maximum spots; elsewhere on the globe, however, better agreement is found.

The figures of Table 1 are graphically shown in Figure 1. Epochs of spot minimum are shown by the arrows at the top of the figure.

TABLE No. 2.—*The extremes of mean annual temperature in United States in the nineteenth century.* [° F.]

Warm years.	Deviation.	Cold years.	Deviation.
1825	+2.0	1835	−1.6
1826	+1.8	1836	−2.6
1827	+0.7	1837	−1.8
1828	+2.9	1838	−1.6
Mean	+1.7		−1.9

Variability in the length of sun-spot cycle.—Köppen and others early recognized that the sun-spot cycle varied irregularly in length. This variability has been and is the source of much difficulty in determining whether or not there is a connection between the two variables—spottedness of the sun and terrestrial temperature.

Schuster [3] with a view of discovering whether or not periodicities could be found in sunspots, subjected all available data thereon to a critical analysis by the process of the periodogram. On dividing the record of sun spots for the period 1749–1899 into two approximately equal parts and analyzing the parts separately he was able to infer that between 1750 and 1820 the 11-year period, though existing, had only a slight intensity, being quite overpowered by two others with periods of about 13¾ and 9¼ years. He also arrived at the conclusion that these two periods were active successively rather than simultaneously, and that of the two periods the one of 9 years was the most important as regards the obervations previous to the maximum of 1788, while that of 13 and 14 years is brought in through the variations observed between 1788 and 1829.

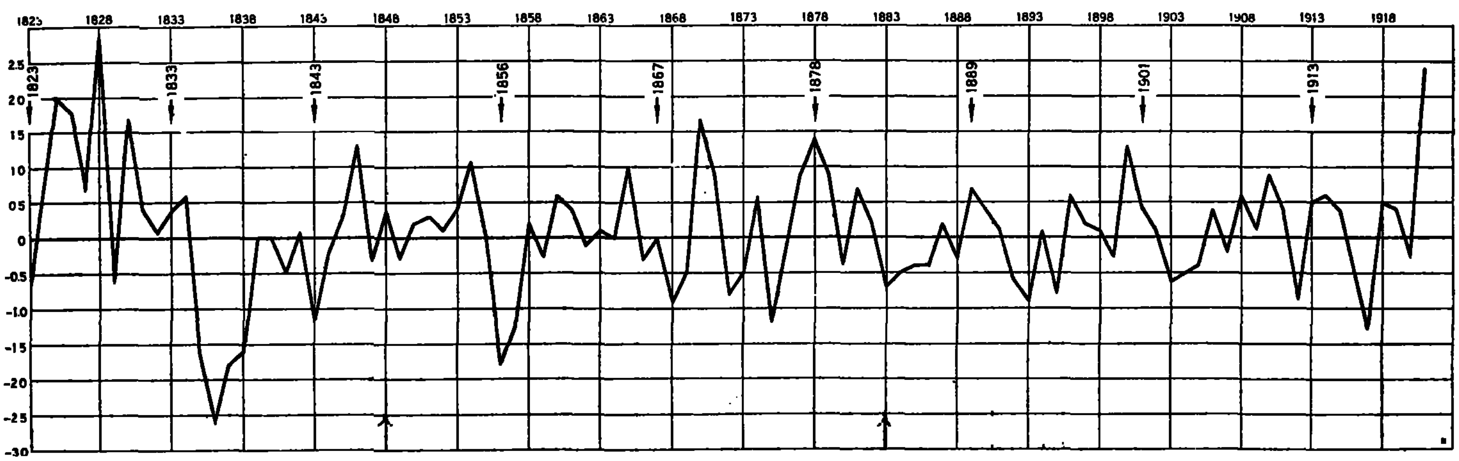

FIG. 1.—Annual deviation of temperature, United States, 1823–1921. Disregard arrows at bottom.

A series of warm years in the United States began in 1825 and prevailed uninterruptedly until 1829; that year was colder than the average by 0.6° F.; then followed five consecutive years with temperature somewhat above the average. A change to lower temperature set in in 1835, continuing through 1836, 1837, and 1838, thus forming the most striking series of temperature

It would seem as if the more or less regular variations showing maxima of intervals of rather more than 9 years were succeeded about 1788 by three unequal but long periods of 17.1, 11.2, and 13.5 years, respectively, and these afterward settled down to a fairly regular

[3] Schuster, A.: On the periodicities of sun spots, *Phil. Trans. Roy. Soc. of London*, A 206, pp. 69–100, 1906.

periodicity of 11.1 years. According to Schuster there is evidence of a number of definite periods. He determined with considerable accuracy the length of three, as follows: 4.79, 8.36, and 11.25 years, respectively.

Before commenting upon the figures of Table 1 it will be helpful to briefly review the results achieved by investigators of the sun spot-terrestrial temperature relations.

The studies of Köppen,[3] beginning with his original paper of 1873 and concluding with his recent paper of 1914, stand in the first rank as regards thoroughness of treatment and the amount of data made available.

He used material from 403 stations distributed over the whole earth, and these he classed by climatic zones. His original conclusions were that in the Tropics parallelism between the variations in the mean annual temperature and those of sun spots is fairly well marked, also that the heat maximum of the Tropics occurs on the average nine-tenths of a year before the corresponding sun-spot minimum and is more retarded with distance from the Equator. The temperature minimum in the Tropics occurs about the time of spot maximum.

In his most recent work this retardation is not so much in evidence as it was in the period 1820–1850, and he now concludes that both within and without the Tropics the heat maximum coincides with spot minimum; in the heat minimum, however, there is in the extra-tropics a slight retardation 0.9 year toward spot maximum.

Newcomb,[4] on the other hand, finds that the maximum of temperature precedes the minimum of spots by 0.3 year and that the minimum of temperature follows the maximum of spots by 0.65 year.

Nordman[5] (1903), using data of 13 stations ranging in latitude from 19 S. to 23 N., concluded that—

> The mean temperature of the earth is subject to a period substantially equal to that of sun spots; the effect of these spots is to diminish the mean temperature of the earth; that is to say, the curve which represents the variations of the latter is parallel to the inverted curve of frequency of sun spots.

Angot,[6] using 16 series of observations, practically the same as those used by Nordman, and treating them by a more rigorous method, concludes as follows:

> In summing up we find that of the 16 series thus studied 14 give for (a) [a constant characteristic of each station and of each period of solar activity] a negative value and 2 a positive value; the probability is then, according to these observations, 7 to 1 that an increase in the number of sun spots is accompanied by a diminution of the temperature and inversely.
>
> By giving to the values of (a) deduced from observations of the various stations, weights proportional to the number of series, we obtain for the final value of (a) —0.0033 C. in the value of the mean annual temperature.

Newcomb (loc. cit.), by a rigorous mathematical method, concludes from an examination of a relatively large number of observations:

> 1. A study of the annual departures over many regions of the globe in equatorial and middle latitudes shows consistently a fluctuation corresponding in period with that of solar spots. The maximum fluctuation in the general average is 0.13 C. on each side of the mean for the tropical regions. The entire amplitude of the change is therefore 0.26 C., or somewhat less than half a degree Fahrenheit. As this fluctuation has ample time to produce its entire effect on the earth, we conclude from it that the corresponding fluctuation in the sun's radiation is 0.2 of 1 per cent on each side of the mean.

Mielke (1913)[7] in an exhaustive study confirmed in large measure the results reached by Köppen in 1873.

Summarizing the foregoing it appears that the weight of evidence is in favor of the existence of a variation in the air temperature of the globe corresponding roughly with that of the spottedness of the sun, an increase in spots corresponding with diminished terrestrial temperatures and vice versa. The amplitude of the variation, is, however, small as has been shown by several investigators and amounts to less than a degree centigrade in the mean of the year.

It is best exemplified in the tropics and is uncertain and difficult to trace in temperate latitudes.

The annual deviations in the United States as shown in Table 1 may now be considered. During the 111 years, 1810–1921, specifically studied the average length of the interval between the epochs of spot minima and the immediately following spot maxima was 4.7 years and the average interval between epochs of minima was 11.5 years.

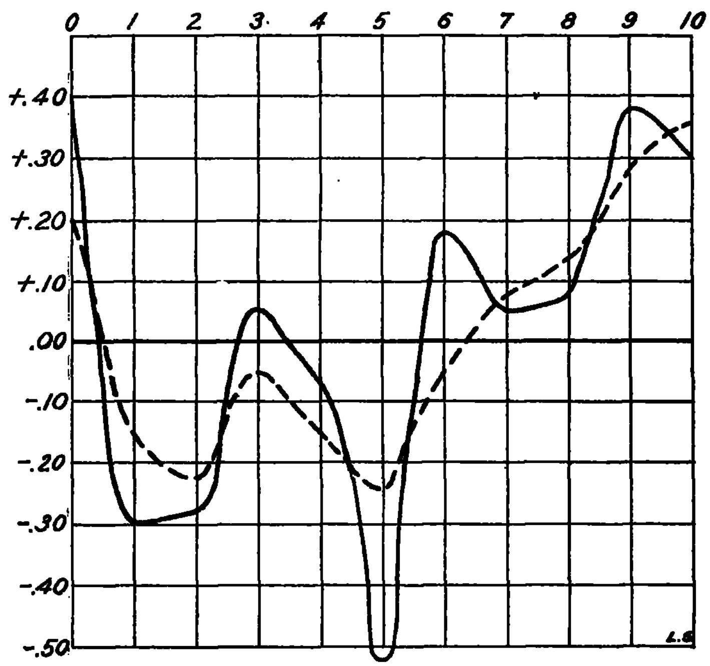

FIG. 2.—Annual deviation in an 11.1-year period. The unsmoothed figures are platted in the full curve, the broken curve is from smoothed values.

For convenience in discussing the data I have assumed a constant sun-spot cycle of 11.1 years and have tabulated the annual departures in horizontal rows of 11 vertical columns in the manner used by some meteorologists in detecting periodicities of a known or suspected length.

The figures appear in the table below and the means of the vertical columns form the curves of Figure 2 the full line being the unsmoothed means and the broken line the same values smoothed by the common formula, $b=\left(\frac{a+2b+c}{4}\right)$.

[3] Köppen, W.: Über mehrjährige Perioden der Witterung, insbesondere über die 11-jährige Periode der Temperatur. *Zeitschr. der Ostereichischen Gesellschaft fur Meteorologie*, VIII, 1873, XV, 1880, XVI, 1881: *Met. Zeit.* VIII, 1891, XXXI, 914.

[4] Newcomb, S.: A search for fluctuations in the sun's thermal radiation through their influence upon terrestrial temperature, *Trans. Amer. Phil. Soc.*, Philadelphia, 1908.

[5] Nordman Ch.: *Comptes Rendus* CXXXVI, Paris 1903, reprinted in MO. WEATHER REV. 31: p. 371, 1903.

[6] Angot, A.: MO. WEATHER REV. 31: 371–2.

[7] Mielke, Johannes.: Die Temperaturschwankungen, 1870–1910, in ihrem Verhältnis zu der 11-jahrigen Sonnenfleckenperiode. *Archiv der Deutschen Seewarte*, XXXVI, No. 3, 1913.

TABLE 3.—*Mean annual temperature deviations within a sun-spot cycle of 11.1 years (the mean for 1867 is combined with the preceding and succeeding years).*

[Figures without signs are plus (+).]

Years.	0	1	2	3	4	5	6	7	8	9	10
1811	1.0	−2.2	−0.4	0.0	−1.0	−1.7	−1.5	−0.6	1.0	−0.1	−0.6
1822	0.9	−0.6	0.6	2.0	1.8	0.7	2.9	−0.6	1.7	0.4	0.1
1833	0.4	0.6	−1.6	−2.6	−1.8	−1.6	0.0	0.0	−0.5	0.1	−1.2
1844	−0.2	0.3	1.3	−0.3	0.4	−0.3	0.2	0.3	0.1	0.4	1.1
1855	0.0	−1.8	−1.3	0.2	−0.3	0.6	0.4	−0.1	0.1	0.0	1.0
1867	0.3	−0.9	−0.5	1.7	0.9	−0.8	−0.5	0.6	−1.2	−0.1	0.9
1878	1.4	0.9	−0.4	0.7	0.2	−0.7	−0.5	−0.4	−0.4	0.2	−0.3
1889	0.7	0.1	−0.6	−0.9	0.1	−0.8	0.6	0.2	0.1	−0.3	1.3
1900	0.4	0.1	−0.6	−0.5	−0.4	0.4	−0.2	0.6	0.1	0.9	0.4
1911	−0.9	0.5	0.6	0.4	−0.5	−1.3	0.5	0.4	−0.3	2.4	......
Means	0.40	−0.30	−0.29	0.05	−0.06	−0.55	0.19	0.04	0.07	0.39	0.30

There is evidence in both curves of the existence of a principal and, indeed, two secondary maxima within the

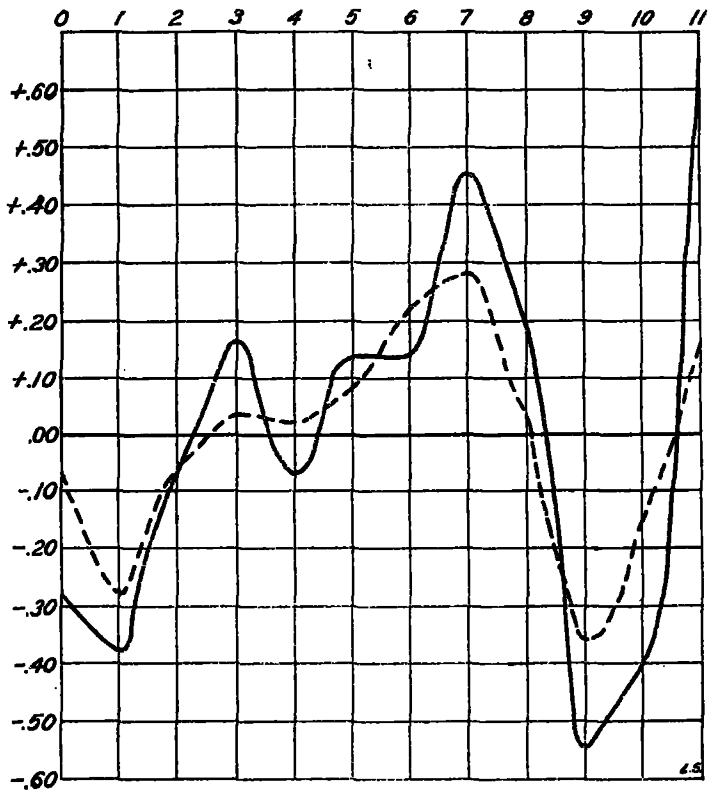

FIG. 3.—Annual deviation in a 12-year period. Full curve unsmoothed, broken curve smoothed values.

11-year cycle. The principal maximum occurs at time of spot minimum according to expectation and the principal minimum of temperature occurs 5 years after the average epoch of spot minimum. The amplitude of the fluctuations is, however, quite small, so small that in order to show it it is necessary to resort to the second decimal place in the means. When we examine the individual values in the table we are struck by the fact that the course of the mean curve is determined by one or more large individual deviations such as occurred in 1825, 1828, 1836, 1837, 1838, 1870, and 1921. The peak of the full-line curve in Figure 2 is reached solely by reason of the great positive departure of temperature for 1921. True the epoch of spot minimum is not far distant. If we combine columns zero and 10 we get 0.35 F. as an average of the heat maximum in the United States on the assumption of an 11.1-year period. This amount is just one-half of the average annual deviation, which as before stated, amounts to 0.7 F. The average of the heat minimum is 0.55 F. and we may say both results are of small significance except from an academic point of view.

As there seems to be some evidence of a 4-year period I have tabulated the figures of the above table in horizontal rows of 12 columns, since both 3 and 4 are multiples of that number.

The results of that tabulation are shown in Figure 3, where, as before, the unsmoothed means are given in the full curve and the smoothed means in the broken curve.

The full curve shows a progressive rise in temperature from zero year to column 7, thence a decline to a minimum in column 9 and a sharp rise to column 11 which corresponds to the 12th year in the series. Curiously all of the entries in that column are positive, which amounts to saying that from 1811 to 1921 the temperature every twelfth year was above the normal. On the whole the results of this tabulation are negative so far as giving evidence of the reality of any periodicity is concerned.

LARGE AREAS VERSUS SMALL AREAS.

The question has arisen is it advisable to use areas of great geographic extent only moderately well covered by observing stations, in preference to smaller areas with a

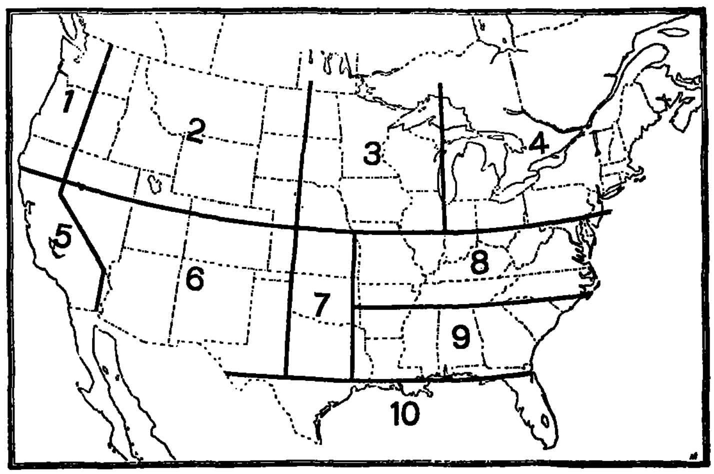

FIG. 4—Subareas in United States used in the computation.

better network of stations. To secure information upon this point I have divided the United States into 10 districts or subareas as shown in Figure 4.

The districts are numbered consecutively from west to east and from north to south. The mean deviation for each district has been computed and the numerical values appear in Table 4 and are presented graphically in Figure 4. The means are unsmoothed and may be compared with the results for the United States as a whole which appear in the curve so marked just below the curve for district No. 6. It is a matter of common knowledge that the Rockies sometimes form an approximate dividing line between regions of positive and regions of negative departures. The order of presenting the curves of Figure 5 is intended to show the deviations west of the Rockies in a group by themselves. Curve No. 1 represents the western part of Washington and Oregon, also northern California. No. 2 the northern Rocky Mountain and Plateau region; No. 5, California south of San Francisco; and No. 6, the southern Plateau and Rocky Mountain region. The effect of oceanic control is seen in districts Nos. 1 and 5.

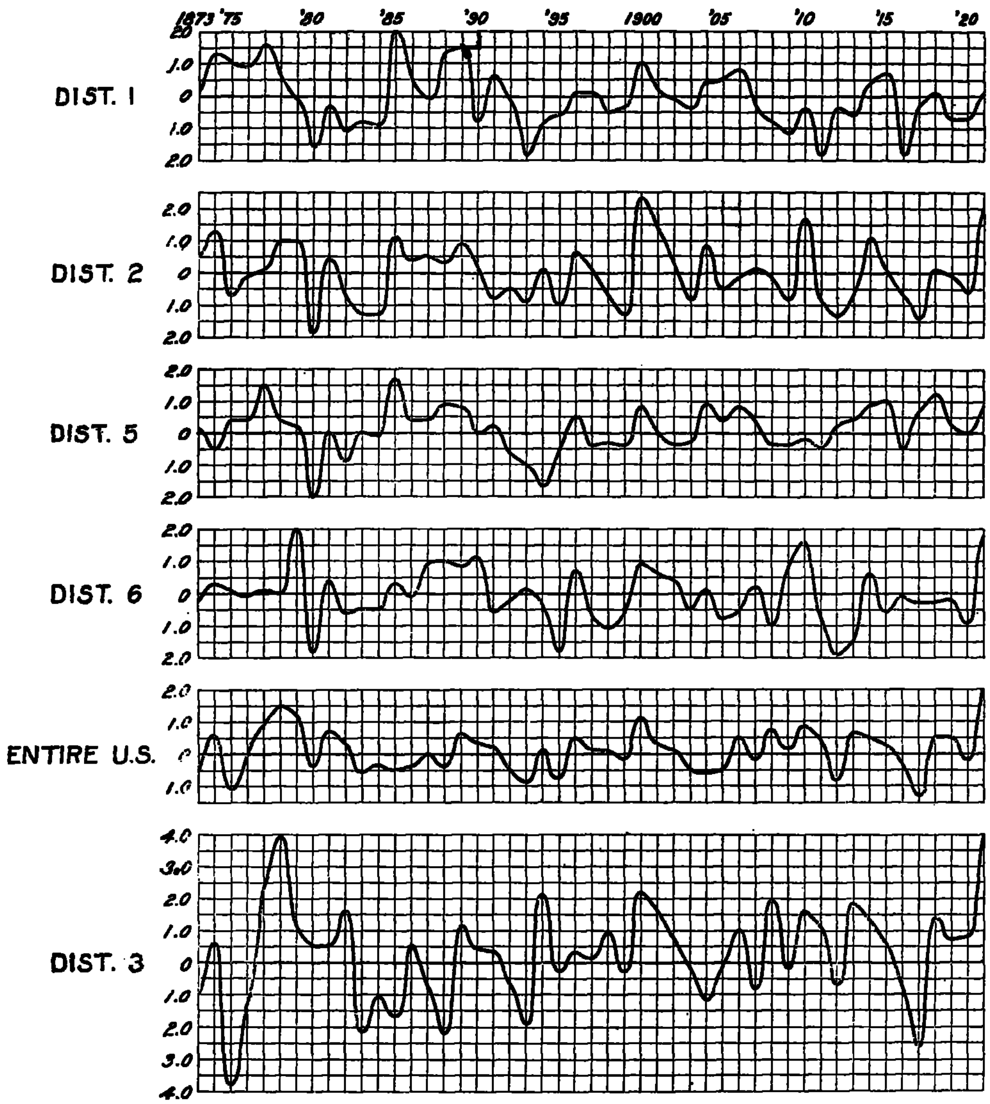

FIG. 5.—Annual deviation by subareas.

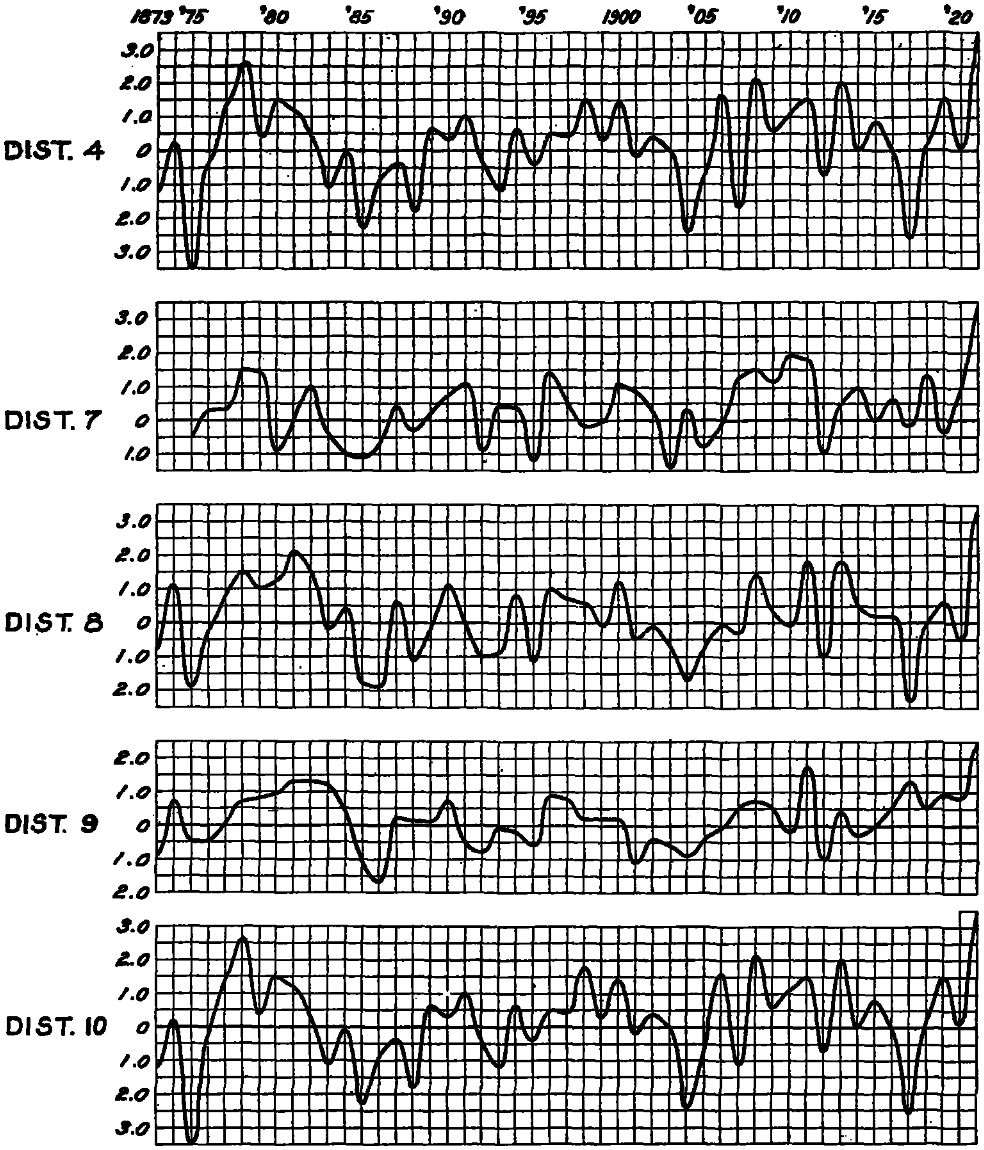

FIG. 5, Continued.—Annual deviation by subareas.

TABLE 4.—*Annual temperature deviations in United States by districts, 1873–1921 (°F.).*

Year.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.
1873	0.2	0.5	−1.0	−1.2	0.1	−0.2	......	−0.8	−0.9	−1.2
1874	1.3	1.3	0.6	0.2	−0.5	0.3	......	1.1	0.7	0.2
1875	1.0	−0.7	−3.8	−3.5	0.4	0.1	−0.5	−1.9	−0.5	[1] −3.5
1876	0.9	−0.1	−1.3	−0.3	0.4	−0.1	0.3	−0.3	−0.5	−0.3
1877	1.6	0.1	2.3	1.4	1.5	0.1	0.3	0.8	0.0	1.4
1878	0.7	1.0	3.9	2.6	0.4	0.0	1.5	1.5	0.7	2.6
1879	−0.1	1.0	1.1	0.4	0.2	2.0	1.4	1.0	0.8	0.4
1880	−1.6	−1.9	0.5	1.5	−2.0	−1.8	−0.9	1.2	0.9	1.5
1881	−0.3	0.4	0.5	1.2	0.0	0.4	0.0	2.1	1.3	1.2
1882	−1.1	−0.7	1.6	0.4	−0.9	−0.6	1.0	1.5	1.3	0.4
1883	−0.8	−1.3	−2.2	−1.1	0.0	−0.5	−0.4	−0.2	1.2	−1.1
1884	−0.9	−1.3	−1.1	−0.1	−0.1	−0.5	−1.0	0.4	0.4	−0.1
1885	2.0	1.1	−1.7	−2.3	1.7	0.3	−1.1	−1.8	−1.1	−2.3
1886	0.5	0.4	0.5	−0.9	0.4	−0.1	−0.7	−1.9	−1.7	−0.9
1887	−0.1	0.5	−0.8	−0.4	0.4	0.9	0.4	0.6	0.2	−0.4
1888	1.3	0.3	−2.2	−1.8	0.9	1.0	−0.3	−1.1	0.1	−1.8
1889	1.5	0.9	1.1	0.6	0.8	0.8	0.2	−0.1	0.1	0.6
1890	−0.8	0.2	0.4	0.3	0.0	1.1	0.7	1.1	0.7	0.3
1891	0.6	−0.8	0.3	1.0	0.2	−1.1	1.1	0.0	−0.5	1.0
1892	−0.1	−0.5	−0.7	−0.4	−0.7	−0.3	−0.9	−1.0	−0.8	−0.4
1893	−1.8	−0.9	−1.9	−1.2	−1.0	0.1	0.4	−0.9	−0.1	−1.2
1894	−0.9	0.1	2.1	0.6	−1.7	−0.4	0.4	0.8	−0.2	0.6
1895	−0.6	−1.0	−0.3	−0.4	−0.5	−1.8	−1.2	−1.1	−0.6	−0.4
1896	0.1	0.6	0.3	0.5	0.5	0.7	1.4	1.0	0.9	0.5
1897	0.1	0.1	0.1	0.4	−0.4	−0.7	0.5	0.7	0.8	0.4
1898	−0.5	−0.7	0.9	1.5	−0.3	−1.1	−0.2	0.6	0.2	1.5
1899	−0.4	−1.3	−0.3	0.3	−0.4	−0.6	−0.1	−0.1	0.2	0.3
1900	1.0	2.3	2.2	1.4	0.8	0.9	1.1	1.2	0.2	1.4
1901	0.2	1.4	1.6	−0.2	0.0	0.6	0.9	−0.5	−1.1	−0.2
1902	−0.1	0.2	0.7	0.4	−0.4	0.4	0.3	−0.1	−0.4	0.4
1903	−0.4	−0.8	−0.2	0.0	−0.3	−1.0	−1.4	−0.7	−0.6	0.0
1904	0.4	0.8	−1.2	−2.4	0.9	0.1	0.3	−1.7	−0.9	−2.4
1905	0.5	−0.5	−0.1	−0.7	0.4	−0.8	−0.8	−0.7	−0.4	−0.7
1906	0.8	−0.2	1.0	1.6	0.8	−0.6	−0.1	−0.1	−0.1	1.6
1907	−0.3	0.1	−0.8	−1.7	0.4	0.2	1.3	−0.3	0.5	−1.7
1908	−0.8	−0.2	1.9	2.1	−0.4	−1.0	1.5	1.4	0.7	2.1
1909	−1.2	−0.8	−0.2	0.6	−0.4	0.8	1.2	0.3	0.5	0.6
1910	−0.4	1.7	1.6	1.1	−0.2	1.6	1.9	−0.1	−0.2	1.1
1911	−1.7	−0.8	1.1	1.5	−0.5	−0.7	1.8	1.8	1.7	1.5
1912	−0.4	−1.3	−0.7	−0.7	0.2	−1.9	−1.0	−1.0	−1.0	−0.7
1913	−0.6	−0.7	1.8	2.0	0.4	−1.5	0.5	1.8	0.4	2.0
1914	0.4	1.1	1.4	0.0	0.9	0.6	1.0	0.5	−0.3	0.0
1915	0.7	0.1	0.6	0.8	1.0	−0.6	0.0	0.2	0.0	0.8
1916	−1.8	−0.7	−0.8	0.0	−0.5	−0.1	0.6	0.2	0.5	0.0
1917	−0.3	−1.4	−2.6	−2.6	0.7	−0.3	−0.2	−2.3	−1.3	−2.6
1918	0.1	0.1	1.4	0.2	1.2	−0.3	1.3	0.5	0.5	0.2
1919	−0.7	−0.1	0.7	1.5	0.3	−0.2	−0.4	1.1	0.9	1.5
1920	−0.7	−0.6	0.8	0.1	0.0	−0.9	0.1	−0.5	−0.8	0.1
1921	0.1	2.0	4.0	3.5	0.9	1.8	3.3	3.3	2.4	3.5

[1] Probably too great.

During the 48 years considered there were three each fairly well pronounced maxima and minima of temperature, respectively, viz, maximum in 1878, 1900, and 1921, and minimum in 1875, 1893, and 1917. The intervals between the maxima were 22 and 21 years, and between minima 18 and 24 years or an average of about 22 years. But even these exceptional years do not show uniform deviations in all parts of the country. In general the deviations are not uniformly in the same sense over the entire area. In many years the deviations on the Pacific coast appear to be damped by the oceanic influence and sometimes they are in the opposite sense from those east of the Rockies, as in 1880, 1885, and 1911.

The foregoing comparison while it does not yield clear cut definite results, serves to confirm the writer in the belief previously expressed,[8] viz, that while terrestrial temperature is primarily controlled by the output of solar radiation the immediate control which results in the day-to-day weather is almost wholly the result of horizontal convection or flow of air from low to higher latitudes and vice versa. In the Bjerknes terminology the continuous shifting of the polar fronts is responsible for temperature changes of much greater magnitude than any which might reasonably be attributed to changes in the intensity of solar radiation. When these changes are integrated over a longer period, say, a month or a year, the net result is often a complex, because the shifting of any series of polar fronts is rarely continuous in one and the same direction but is made up of a series of advances and retreats of unequal extent and duration. It occasionally happens that the advance of equatorial air, or, more correctly speaking, air from middle latitudes, toward the polar regions is not seriously checked for so long a period as a month. Naturally that month is unduly warm with respect to the seasonal normal and the excess warmth is reflected in the annual mean. The remainder of the year may have been close to the normal.

This warns us that the year as a time unit is too long and that the region to look for evidences of a relation between terrestrial temperature and sun-spot activity is not in that portion of the Temperate Zones which comes within the influence of moving cyclones and anticyclones but rather in the Tropics as already suggested by a number of writers.

The negative result reached in the foregoing was not unexpected; it may have been due to one or more of a number of causes which for convenience may be stated in the form of questions: (1) Do temperature observations near the surface of the earth throw any light upon the original intensity of radiation emitted by the sun? This is fundamental. (2) How shall allowance be made for lack of observations from the tropical oceans? (3) In what degree are land observations to be used as an index of the air temperature of the globe? (4) Is it a fact, as some have assumed, that an increase in the intensity of solar radiation will first warm the upper air (the stratosphere) and that the heat so communicated will later warm the lower layers of the atmosphere (the troposphere)? (5) Is the absorption of solar radiation by the earth's atmosphere so clearly understood as to permit proper allowance to be made for it? And finally (6) the evidence since 1883 seems to indicate that when a quantity of volcanic dust is shot into the very high atmosphere as in 1883, 1912, and 1903 surface cooling results. The course of the curve in Figure 1 seems to support this view and pyrheliometer observations since 1903 also lend support to it.

[8] MONTHLY WEATHER REVIEW 4. 49:67.